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Paper Session II-B - A Strategy for the Initial Wetting of a Plant Cultivation Unit in Space

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A Strategy For The Initial Wetting Of A Plant Cultivation Unit In Space

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Abstract

NASA seeks to utilize plants to recycle air, water, wastes, provide food and contribute to the psychological well being of the crew during prolonged space flight missions. We believe that the provision of adequate levels of water (without causing water logging) and oxygen to the root zone are the most crucial components holding back major advancements in this area. As part of the Microgravity Plant Nutrient Experiment (MPNE-02) space flight investigation, the plant growth hardware will be launched in an unpowered, dry condition and initiated by the crew on-orbit. We report here on preliminary efforts at developing a strategy for the initial wetting of the root zone substrate based upon the use of moisture sensor-provided feedback control to the water input control mechanism. The ability to initially wet, in a uniform fashion, the plant culture root zone substrate under microgravity conditions will be a critical operational requirement for all long-duration plant growth efforts in space.

Background Information

There are currently two "primary" candidate nutrient delivery systems (NDS') being considered for microgravity (µg) based plant culture: (1) the porous tube NDS (Dreschel and Sager, 1989; Dreschel, 1990; Dreschel *et. al*., 1992; Dreschel *et. al*., 1993; Tsao *et. al*., 1996; Levine *et. al*., 1999), and (2) substrate-based NDS' (Morrow *et. al*., 1994; Bingham *et. al*., 1996; Goins *et. al*., 1997; Levine, 1999). The Microgravity Plant Nutrient Experiment (MPNE-02) space flight investigation will fly both of these options in a side-by-side comparison. The scientific rationale for this experiment relates to the dominance of the surface tension of water under µg conditions, which has often been found to lead to either severe water-logging or excessive drying in the root zone of the various plant culture hardware thus far available for space experimentation efforts. Consequently, differences in plant growth responses between space flight experiments and their ground controls are obtained based upon differences in moisture distribution patterns between the two conditions (Levine and Krikorian, 1996; Jones and Or, 1998). Until we have a better means of controlling these critical aspects of plant culture, many of the differences determined by investigative endeavors will be called into question as to whether they are related to "direct" effects of µg or merely "indirect" effects attributed to a µg-altered culture regime. The latter produces results less optimal than if the growing conditions had been specifically tuned to accommodate space flight conditions.

The MPNE-02 experiment will address the question of "comparability of environmental conditions" between the flight and ground control experiments by employing a minimum of three different porous tube and substrate wetness levels. It is anticipated that different pre-set wetness levels than those used on Earth will be required to support optimal plant growth in space. Dry seeds will be loaded three days prior to Orbiter lift-off, and the system will be initiated by the crew on-orbit. A minimum of 72 wheat (*Triticum aestivum*) seeds will be imbibed and germinated within both NDS', and time-lapsed video of the plants will monitor growth over time.

Critical to this endeavor is an understanding of the dynamics of water delivery and distribution under both 1g and µg conditions. Data sets which address these questions were obtained during the Astroculture-I (Morrow *et. al*., 1994) and Greenhouse-II (Bingham *et. al*., 1996) space flight experiments, in which substrate-inserted moisture sensors generated the data diagrammatically represented by the patterns presented in Figures 1a,b (Jones and Or, 1999). In this depiction of the

root zone, the effect of μg can be seen to produce the highest concentrations of water immediately adjacent to the centrally situated water input tube, and decreasing wetness levels with increasing distances from the water input tube (Figure 1a). In contrast, under 1g conditions (Figure 1b), the effect of gravity was to pull the water down to the bottom of the plant culture tray, resulting in an entirely different water distribution pattern.

These patterns can be used to address the question of how to design the water delivery system for both space flight and ground control plant culture units. The argument has been made that different placements of the water input tubes for μg and 1g operation would be the best way to optimize system performance for both conditions. However, there is a compelling justification to make the design the same for both units, i.e., so that the option to use the ground control unit would be available in the event of a pre-flight hardware failure in the flight unit. If it is therefore assumed that both the flight and ground units will possess the same configuration, there are three alternative placement locations for the water input tubes: (1) at the top, (2) middle, and (3) bottom of the plant trays.

For 1g operation, the optimal location for the water input tubes would be near the top of the root zone so that water would percolate downward and uniformly wet the substrate (similar to the natural case in a field after a heavy rain). However, such a location would produce excessively wet upper layers in μg, and relatively (or completely) dry lower substrate layers. A middle-situated water input tube would result in the patterns already discussed in Figures 1a,b. Clearly this represents a drastically different growing regime for the space flight vs ground control experiments, and would confound any attempt at discerning "direct" μg-related effects on plant growth and development. In contrast, if the water input tubes were situated at the bottom of the root zone, the trays could be completely flooded at experiment start-up and then the excess water removed under both 1g and μg conditions. We present a hypothetical case for such a flooding regime scenario in Figures 1c,d,e,f,g,h. In both the μg (Figures 1c,e,g) and 1g (Figures 1d,f,h) cases, a complete flooding of the root zone would be possible. And in theory, a subsequent draw-down or removal of the excess water would result in a uniformly wetted substrate which would approximate "field capacity" conditions.

Methodology

As depicted in Figure 2, our proposed approach would utilize a water input tube which is closed on one end and situated at the bottom of the plant tray. Water would be pumped into the other end to gradually flood the substrate tray. The excess water would then be removed from the plant tray, leaving behind a uniformly wetted substrate without any excessively dry (or wet) areas.

To assess the ***technical feasibility*** of this approach we constructed the following test system (Figure 3). One heat-pulse moisture sensor (described below) was situated with its tip 1 cm below the surface of the substrate (Turface prescreened to 1-2 mm) within a tray approximating the maximum dimensions of that currently under consideration for the MPNE-02 substrate NDS (24 cm long x 14 cm wide x 4 cm high). While we are by no means suggesting that any system rely upon the use of a single moisture sensor (a three dimensional array being much preferable), for this preliminary effort we restricted our efforts to a single sensor. The moisture sensor was connected to a data logger-PC control system and “instructed” a peristaltic pump to fill the plant tray until the moisture sensor’s setpoint (100% Relative Water Content, see below) was achieved, at which point the peristaltic pump was reversed to drain off any excess water within the plant tray. The entire tray was situated on top of a scale, and water was drawn from a 2 liter graduated cylinder, thus we were able to track water introduction and withdrawal for the tray based upon changes in tray weight and reservoir volume.

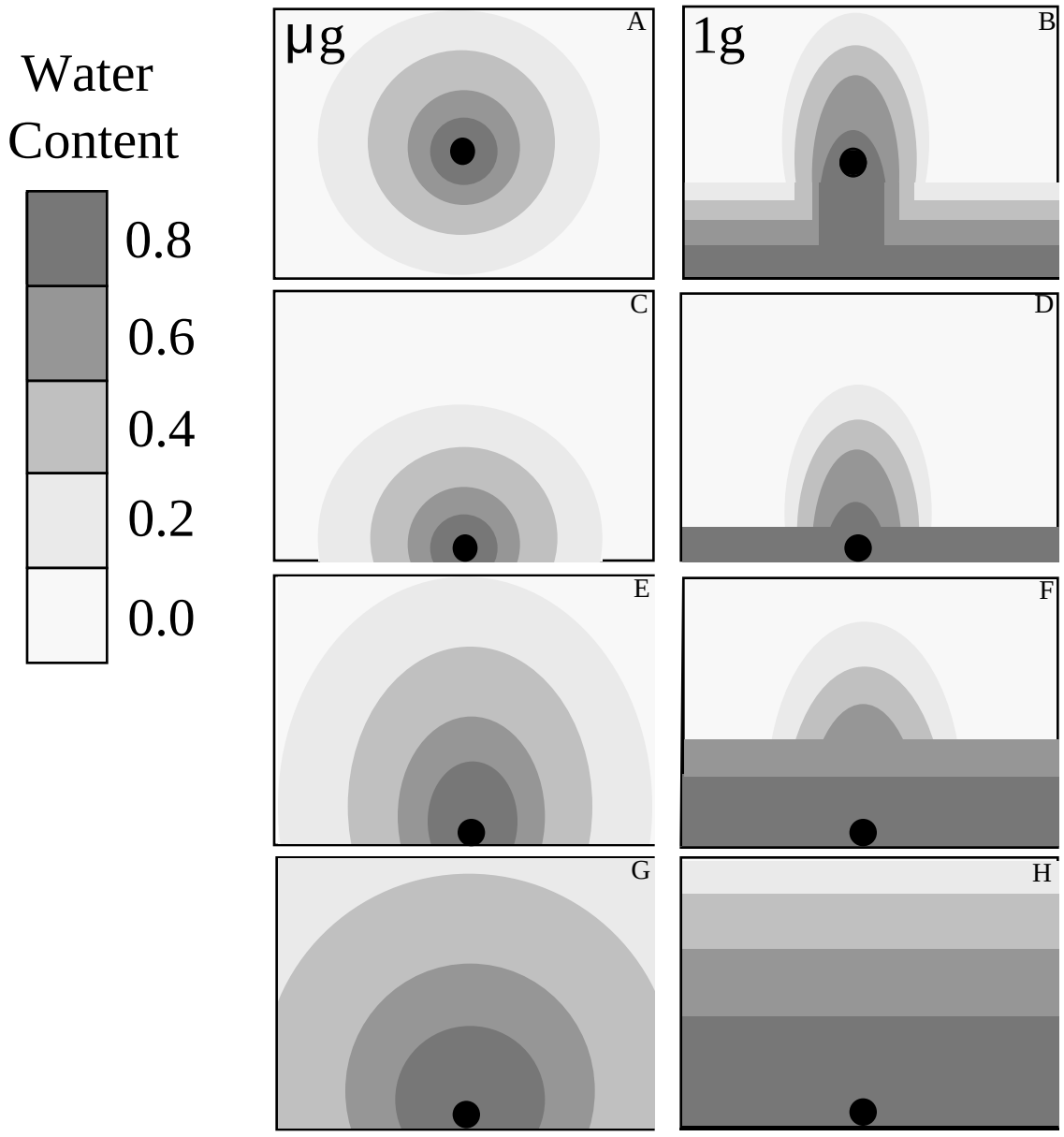


Figure 1. A cross-sectional diagrammatic representation of moisture distribution patterns obtained in space (a) and on the ground (b) within substrate-based plant culture trays possessing a centrally located water input tube (adapted from Jones and Or, 1999). Also presented are speculated moisture distribution patterns for the flooding cycle in both the µg (c,e,g) and 1g (d,f,h) cases where the water introduction tubes are situated on the bottom of the plant trays.

The heat pulse moisture sensor (Figure 4a) worked as follows. A fixed 12 volt current was supplied for a defined time interval (30 seconds). A resistive heater produced a heat pulse which caused a temperature rise in the substrate surrounding the probe. This temperature rise was measured with a Resistance Temperature Detector (RTD). The change in temperature was logged and used in conjunction with moisture probe calibrations (see below) to determine the Relative Water Content (RWC) of the substrate (since heat dissipation was a function of substrate wetness level).

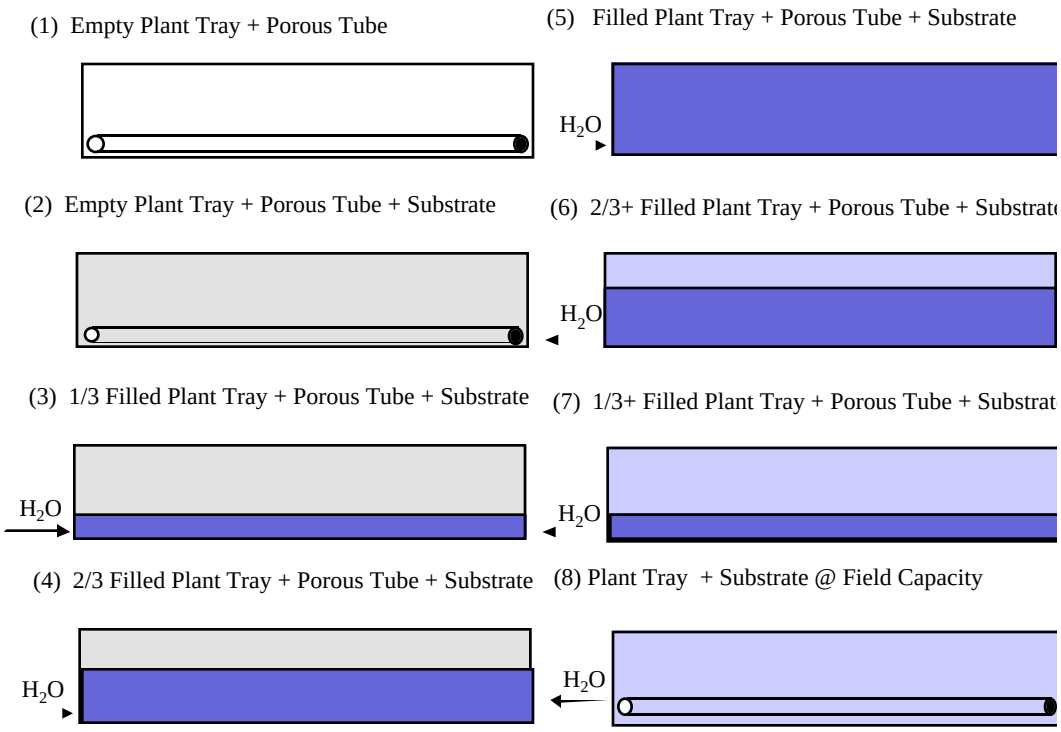


Figure 2. Diagrammatic representation of proposed plant tray wetting scenario based upon a bottom-up flooding cycle followed by a draw-down phase in which excess water is removed from the plant tray.

Moisture sensor calibration consisted of the following steps: (1) A moisture probe temperature calibration regression was obtained (Figure 4b) by comparing probe temperatures with known (thermometer-based) water bath temperatures. (2) The substrate was placed (packed) into an insulated beaker and time allowed for temperature equilibration between the substrate and the ambient environment. (3) The moisture probe was inserted and the substrate packed down around it. A "dry" measurement (?T value) = 0% RWC was obtained. (4) The beaker was filled with water until the surface of the top-most substrate layer was just shining, i.e., all pores between substrate particles were filled = 100% RWC, and the ?T value was obtained. (5) The beaker was emptied, dried and refilled with packed substrate plus half the volume of water used in step 4. It was then mixed well and the moisture probe quickly inserted and the 50% RWC ?T value obtained. Additional calibration points at different RWC values were obtained. The ?T vs RWC linear regression (Figure 4c) was then generated.

Figure 3. Substrate wetting study test apparatus. See text for details.

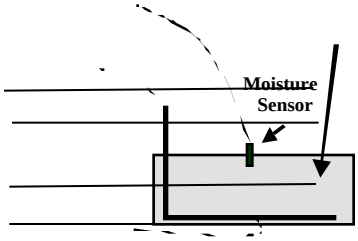
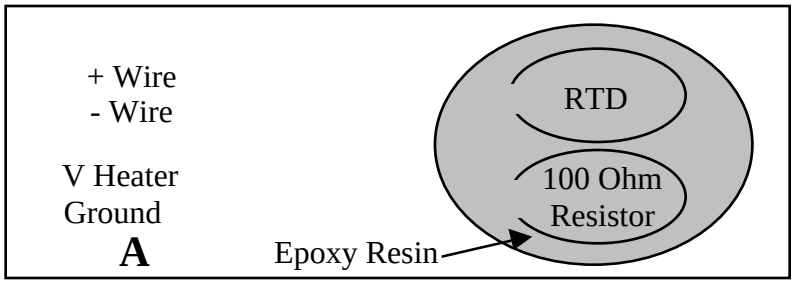
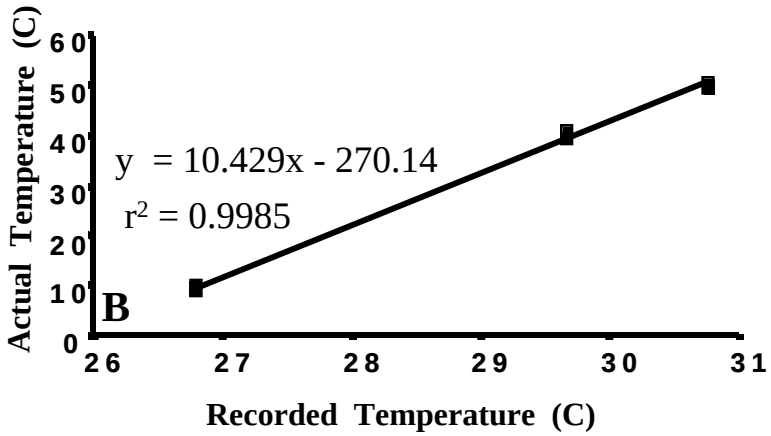


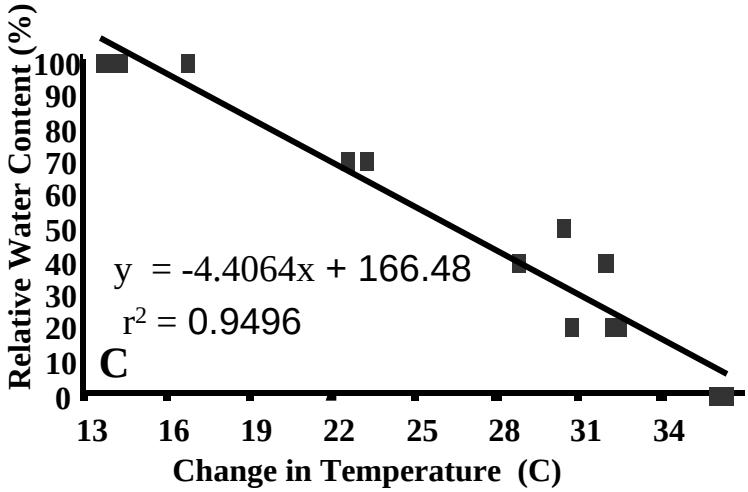
Figure 4. Moisture sensor operation and calibration. A. Moisture sensor construction. B. Moisture sensor temperature calibration. C. Relative water content regression.



Results

Figure 5 presents data which were both logged and recorded during wetting study. recordings of water within the to track the sensor's level of (computer the water half) and half) portions of Midway through removal cycle sensor (which old) failed, but interfere with operation of the which continued reverse (i.e., water) for the study.





Moisture sensor calibration. A. construction. B. temperature Relative water calibration

presents data automatically manually the substrate Manual the amount of tray can be seen moisture saturation logged), both on addition (left removal (right the graph. the water the moisture was ca 4 years this did not the normal peristaltic pump to pump in remove excess duration of the

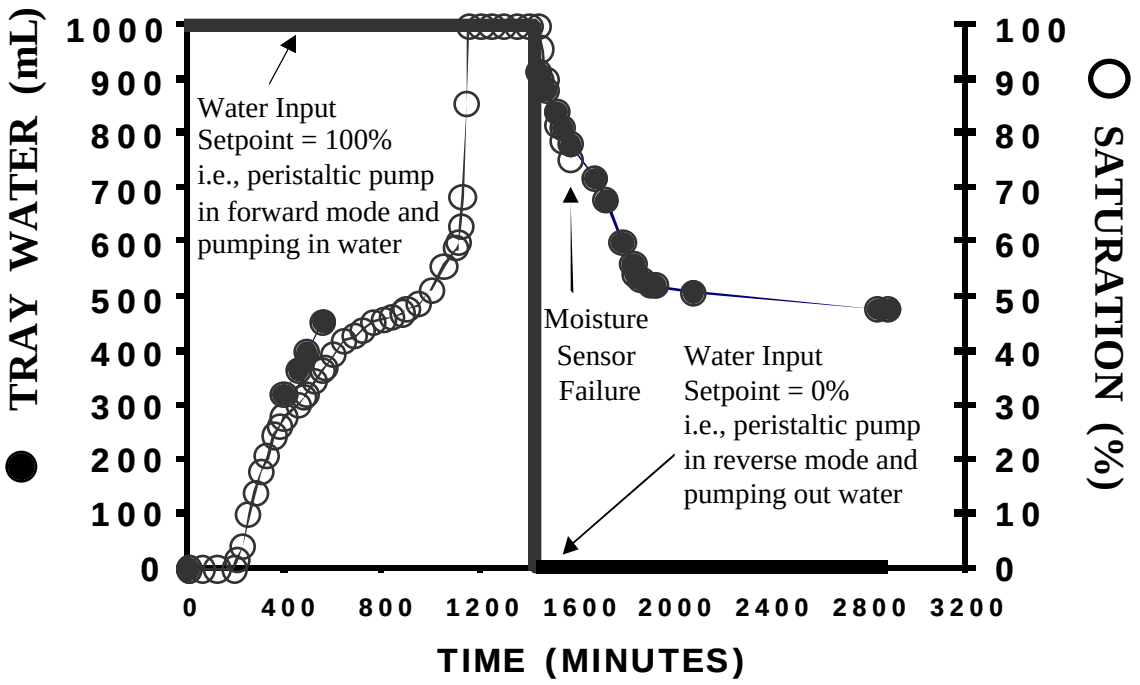
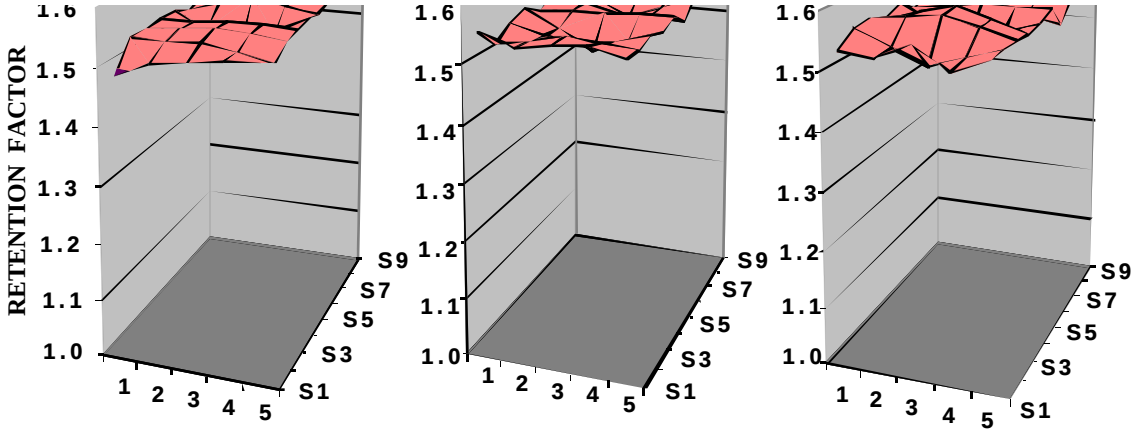


Figure 5. Moisture sensor saturation and volume of water delivered to plant tray over time.

At the completion of the drainage phase, 33 evenly distributed vertical core samples were taken throughout the substrate and split into: (1) bottom, (2) middle, and (3) top segments. Each segment was weighed wet, subjected to a 48 h drying interval at 70° C and reweighed dry. A retention factor (wet weight/dry weight) was then calculated for each segment, which is a ratio reflecting the amount of water (in grams) associated with each gram of substrate (Levine and Krikorian, 1996). The core samples revealed a relatively uniform moisture distribution pattern throughout the substrate (Figure 6). There were neither any "dry" areas, nor any excessively wet areas found within the root zone.

Figure 6. Moisture distributions patterns in the top, middle and bottom layers of the substrate after water removal. The y-axis scale ranges from a completely dry substrate (Retention Factor = 1.0) to 0.6 grams of water per gram of substrate (Retention Factor = 1.6). See text for details.



Discussion

The ability to initially wet, in a uniform fashion, the plant culture root zone substrate under microgravity conditions will be a critical operational requirement for all long-duration plant growth efforts in space. We report here on preliminary efforts at developing a strategy for the initial wetting of the root zone substrate based upon the use of moisture sensor-provided feedback control to the water input control mechanism. Critical for the proposed approach was the ability to discern exactly when the upper layers of the substrate became wet. We therefore assessed the utilization of a substrate-inserted moisture sensor in this capacity. Also evaluated was the use of the moisture sensor for the provision of feedback control to the water input control mechanism, which in this instance was a peristaltic pump, but which could be a variety of alternative devices (solenoids, syringe pumps, etc.) The substrate-based NDS prototype successfully tested a bottom-up flood and subsequent draw-down approach to go from a completely dry substrate to a substrate under "field capacity" (i.e., without any dry or excessively wet spots) conditions. This experiment also demonstrated the feasibility of utilizing feedback from moisture sensors to regulate the ***initial*** wetting of substrate-based nutrient delivery systems. After flooding and draw-down, which initiates seed imbibition, a separate means of controlling substrate wetness level will be invoked. One promising approach would be the use of the moisture sensor measured wetness level to control water input as needed.

Acknowledgements

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